International Research Journal of Insect Sciences
2025 Vol. 10, No. 1, pp. 1-17
ISSN(e): 2408-9281
ISSN(p): 2412-3439
DOI: 10.18488/irjis.v10i1.4455

Impact of weather constraint on tomato leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera: gelechiidae) phenology in field and greenhouse investigations

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Article History
Received: 8 August 2025
Revised: 19 September 2025
Accepted: 29 September 2025
Published: 7 October 2025

Keywords
Degree days
Relationships
T. absoluta
Temperature
Thermal units
Weather.

ABSTRACT

In the global climate, a higher temperature increase than in recent decades is expected, especially affecting insects susceptible to the hottest summer events, such as the tomato leaf miner *Tuta absoluta* (Meyrick), which is responsible for severe tomato yield losses. Samples were taken from fields and greenhouses. Larvae collected were kept in the laboratory at various constant temperatures to investigate the effects on development and mortality of the immature stages and to determine the thermal units required for development in relation to the minimum and maximum daily temperatures (DDs) over several months. The Daily Degree Units (DDU) results for the generation of *T. absoluta* per year were 404.46, 313.67, 404.46, 374.13, and 441.79 for Menufia, Sharkia, Kalubia, Dakahlia, and Giza, respectively. Temperature correlation values for the same locations ranged from 0.789, 0.78, 0.594, 0.736, and 0.72. The relationship with rainfall was positive and significant. Non-significant values were found for mean temperature, relative humidity, and bright sunshine hours. This work aids in the prediction of generation times, the number of generations per year, and the development rate of each generation at different times and locations, both for current and future years.

Contribution/Originality: This study document's statistical observation contributes to predicting population growth rates in thermally variable environments by using degree days to quantify species persistence, heat or cool tolerance, population dynamics, and pest emergence phenology. It is directly related to the history of insecticide resistance, timing of application, and selecting the appropriate compound.

1. INTRODUCTION

Numerous studies have been conducted to identify trends caused by climate change and global warming, which are among the most significant issues of our time [1]. Climate change may affect the abundance of agricultural harmful organisms [2]. The most important requirements are research to predict the effects of biotic and abiotic factors; the percentage of survival over time and the ability of individuals to overwinter or spawn offspring in the population. Climate change is creating new ecological niches, which offer opportunities for pests to breed and spread in new geographical areas and migrate from one region to another [3]. Although the climate has been observed for many years, the weather also provides information on the same climatic factors. Schedule monitoring is also necessary because of the lack of information on the occurrence and activity of the harmful organism (spatial and temporal pattern and variations). The most important factors for aiding in losses caused by the invasion of tomato crops by *T. absoluta* are the time of year, which coincides with high summer temperatures of 35-40 degrees, affecting population density and abundance percentages and causing yield losses of up to 100 percent [4]. The life cycle of this insect is approximately 12 generations per year, depending on environmental conditions, with a high rate of egg laying and reproduction. The origin of *T. absoluta* was reported in 2006 in South America, and it has been observed in Spain and in Africa over the last 10 years, including countries such as Algeria, Morocco, and Tunisia. Other climatic factors, such as wind, humidity, storms, frost, heavy rainfall, and food availability, also limit population growth and the success of Integrated Pest Management programs, particularly influencing pesticide application decisions [5, 6]. Predicting insect phenology or development rate under different constant temperatures is an urgent need for prediction research [7]. Insect species have an exceptional temperature-related development requirement depending on their biogeographic zone and require a consistent amount of heat accumulation to reach certain life stages. Calculate the optimum and lethal temperature for insect development from daily information on maximum (Max) and minimum (Min) temperature, and conclude the unit of accumulated temperature over time (days in degrees). The accumulated days of the day are used to predict important events in the insect life cycle such as egg laying, hatching, reproduction, migration, population formation, and dynamics over a shorter period of time, providing accurate predictions. This study was conducted to demonstrate the relationship between *T.absoluta* on tomato plants from population monitoring in field and greenhouses and certain climatic conditions in specific years and seasons.

2. MATERIALS AND METHODS

2.1. Insect Bases

Certain infected tomato leaves containing immature stages, selected randomly from 100 infected plants, were collected from fields in large tomato production areas in specific governorates (Sharkia, Kalubia, Menufia, Dakahlia) and from greenhouse farms during the period 2018-2023. The collection was conducted at seven constant temperatures over seven months. The leaves contained empty mine fragments and immature *T. absoluta*. For further studies, samples were transported to the laboratory and kept under stable conditions at 27°C and RH 70. For each experiment, larvae were taken immediately from the infested leaves.

2.2. Insect Rearing

Each larva normally feeds on the original tomato leaves until the pupae emerge, and then the fresh leaves are replaced by the bull larva from the old plant, if necessary. Each some leaves of the tomato plant are placed in large glass containers until the pupa emerges, and the pupae are collected, gently picked, and placed in the large glass containers until the adult emerges. Adults are fed on sucrose solution through a piece of cotton soaked. Dead adults are promptly removed, and a glass container filled with fresh tomato leaves is used to feed the newly hatched larva.

2.3. Survival at Various Temperature

Each collected larval group raised for optimal and threshold temperature (lethal temperature) by raising larvae in stable conditions represents the temperature conditions in the field (10, 15, 20, 25, 30, 35, 40, and 46 degrees Celsius). In addition, a large number of *T.absoluta* larvae are bred for the calculation of the accumulated heat requirements for the entire generation by the DD method over a period of several months, against maximum and minimum temperatures.

Accumulated heat unit and DD calculated as follows:

In principle: Max and Min temperatures data were used to compute heat units by the following formula: days (DD) = d(t - t0) and d = DD / (t - t0), where d = developmental duration of the egg-to-adult life stage and t = temperature (temperature of the test). The number of heat units required for complete generation from egg to adult emergence = DD - C, where DD is the accumulated heat units and C is the threshold temperature. In an alternative way, the Daily Degree Units (DDU) = [(Max Temp. − Min Temp.) / 2] - threshold.

This a method of determining limitations for the effective accumulated temperature.

Additionally, the thermal constant was calculated as follows: y = n(t − x).

Where y is the thermal constant (total average temperature required for the development of each stage). X is the thermal threshold, and n is the average duration for the development of the stage at temperature t. In addition, prediction of generation time and the number of generations per year is calculated as follows: DDU / constant temperature.

The rate of generation development at any temperature G= n (t−x)/y.

Where n = number of days per month, t = temperature, x = developmental zero, y = thermal constant.

All formulas used in this study were according to some literature cited; this issue was Logan et al. [8], Briere et al. [9], and Abolmaaty et al. [10].

2.4. Weather Factors for All Sampling Locations

The temperature detected as minimum and maximum (°C) as the monthly average, and the relative humidity (RH percent) recorded by a hand thermometer in the tested governorate. In addition, all tested geographic locations weather constraints obtained from weather prediction websites, such as the URL (https://weatherspark.com) and https://en.climate-data.org/africa-egypt. provide monthly and daily data for all years for the governorates. Some websites provide forecasts for 2050- 2100, introducing validated and implemented weather specific data, such as World Bank Climate Change Knowledge Portal (WB CCKP) [11]; WHO [12]; ClimateWatch [13] and Negi et al. [14]. And some downloaded from https://climateknowledgeportal.worldbank.org/country/egypt/climate-data-projections-general. And this website, https://www.visualcrossing.com/weather-quer.

2.5. Statistical Analysis

All statistical analysis was accomplished using SPSS software for ANOVA analysis of significant differences exploration between and among places and times of test. In addition, multiple linear regression was undertaken to evaluate the effects of some weather factors on the slope of *T. absoluta* population fluctuation. Furthermore, tests of significance of the correlation coefficient of multiple determination and the probability of accepting the null hypothesis of both (P-value) were estimated. The DDU calculation was completed using an Excel worksheet as Elnesr and Alazba [15] and others.

3. RESULTS AND DISCUSSIONS

3.1. Population Changes Based on Accumulated Heat Unit

Insect development is temperature-dependent, requiring a specific measure of heat accumulation between lower and upper developmental limits and the optimal development point. A lot of information is required, such as life cycle, lethal temperature for mortality at each life phase, and the dynamic change or prediction of *T. absoluta* population, abundance, or generation rate per year at different temperatures. Different constant temperatures therefore influence the development and mortality of the various immature stages of tomato leaf miner, *T. absoluta*, through the accumulation of thermal units required for development in relation to days (DD days). The results showed that *T. absoluta* can develop strongly from 20 to 35°C. High survival and fecundity were observed at 25°C. This means that the upper and lower temperature range for development is 15 and 35℃ (Table 1) and requires 440.9 DDU to complete its life-cycle (Table 2). All these data were obtained from larvae collected from samples gathered from different governorates at various temperatures and are shown in Table 1. The first hatching of eggs occurred at 13℃, and the first emergence of adults was observed at 19℃. The incubation period of the eggs ranged from 13 to 3 days at laboratory-adapted constant temperatures between 10 and 45℃. The larval stage lasted from 17 to 6 days, the pupal phase from 10 to 2 days, and the total duration from egg to adult ranged from 57 to 14 days. The results of this study concur with those of Abdel Kareim et al. [16], Negi et al. [14], Cuthbertson et al. [17], and Tabikha [18].

Table 1. Duration of *T. absoluta* stages under various temperatures in the lab and mortality percentage estimation of Giza greenhouses in 2023.

Temperature: °C	Stage duration (days)				Total Duration	Fecundity	Mortality numbers at tested				Total
	Egg	Larvae	Pupae	Adults			Egg	Larvae	Pupae	Adults	
10	13	17	10	17	57	105	32	28	10	20	90
15	9	17	9	20	55	315	22	20	10	18	70
20	7	12	9	10	38	693	10	10	7	7	34
25	5	11	8	6	30	840	5	6	5	4	20
30	4	10	6	6	26	1050	0	0	0	0	0
35	3	9	5	4	21	1050	0	0	0	0	0
40	3	7	3	3	16	945	2	4	4	0	10
45	4	6	2	3	14	892.5	2	5	5	3	15

Note: Fecundity = Eggs laid per female.

3.2. Thermal Units Accumulation

Temperature unit data by monthly average minimum and maximum temperature for each governorate are summarized in Table 2. The data revealed different heat units obtained in different months, and *T. absoluta* should be developed by accumulating heat units and combining data for the species. The winter months have a small thermal unit, while the summer months have a large thermal unit. The total temperature unit for all locations ranged between 81 and 94 °C per year, which allowed for pest evolution in Giza, Kalubia, Menufia, Dakahlia, and Sharkia to range from 6.4 to 8.6 °C per year (Table 2). The trend under these conditions started with a level of 2.3 in the winter months and reached 2.3 in the summer months, with a level of 1.2 in July (Table 2).

The constant temperature values for all governorates were 165, 142, 180, 153, and 172. The minimum thresholds (Zero growth development thresholds) were 5.5, 4.75, 6.0, 5.13, and 5.75 for Menufia, Sharkia, Kalubia, Dakahlia, and Giza, respectively. These figures are in line with Salama et al. [19], Abdel Kareim et al. [16], and Damos et al. [20].

Table 2. Calculated thermal units, minimum threshold, and constant temperature according to the monthly average of minimum and maximum temperatures of each governorate.

Thermal units												
	Janua.	Feb.	March	April	May	June	July	August	Septe.	Octob.	Nove.	Decem.	Average
Menufia	-0.5	0.5	3	7	10	13	14	14	13	9.5	5	1	90
Sharkia	-1	0	2.5	6	9	12	14	13.5	11.5	8.5	4	0	81
Kalubia	-0.5	1	3	7	10	13.5	14.5	15	13	9.5	5	1	92.5
Dakahlia	-0.5	0	2.5	6	9.5	12.5	13.5	14	12.5	9.5	5	1	86
Giza	-0.5	1	3.5	7.5	10.5	13.5	14.5	14.5	12.5	10	5	1.5	94
Dev.rate	2.3	2.4	2.4	2.2	1.9	1.45	1.2	1.4	1.42	1.86	2.22	2.33	--
Min threshold													
Menufia	-8.5	-7.5	-5	-1	2	5	6	6	5	1.5	-3	-7	5.50
Sharkia	-9	-8	-5.5	-2	1	4	6	5.5	3.5	0.5	-4	-8	4.75
Kalubia	-8.5	-7	-5	-1	2	5.5	6.5	7	5	1.5	-3	-7	6.00
Dakahlia	-8.5	-8	-5.5	-2	1.5	4.5	5.5	6	4.5	1.5	-3	-7	5.13
Giza	-8.5	-7	-4.5	-0.5	2.5	5.5	6.5	6.5	4.5	2	-3	-6.5	5.75
Constant temperature													
Menufia	-255	-225	-150	-30	60	150	180	180	150	45	-90	-210	165.00
Sharkia	-270	-240	-165	-60	30	120	180	165	105	15	-120	-240	142.50
Kalubia	-255	-210	-150	-30	60	165	195	210	150	45	-90	-210	180.00
Dakahlia	-255	-240	-165	-60	45	135	165	180	135	45	-90	-210	153.75
Giza	-255	-210	-135	-15	75	165	195	195	135	60	-90	-195	172.50

3.3. Number of Generations of Each Sample Site

And the generation number data for each month is shown in the Table 3. In addition to the generation days used by *T.absoluta* in the different governorates, the following table is also available: We can see that the positive number of generations in each month was different, certainly due to the temperature effect of that period of the year, and that the sum of these gives the number of generations in each year. Generation per year ranged from 8.6 to 6.4 for Giza and Sharkia (Table 3). The *T. absoluta* generation days by temperature site varied, with a large number of days in the winter months (reaching 54 days in January) and a range of 16 days in the summer months (Table 4), indicating a large variability of temperature preference. These results are in line with those of Salama et al. [19] and of Abolmaaty et al. [10].

Table 3. Number of generations/months for all *T. absoluta* samples from field and greenhouse.

Places	Janua.	Febr.	March	April	May	June	July	August	Septe.	Octob.	Nove.	Decem.	Gen/year
Menufia	-2.7	-2.3	-1.56	-0.3	0.63	1.56	1.88	1.88	1.56	0.47	-0.94	-2.19	7.98
Sharkia	-2.8	-2.5	-1.72	-0.6	0.31	1.25	1.88	1.72	1.09	0.16	-1.25	-2.5	6.41
Kalubia	-2.7	-2.2	-1.56	-0.3	0.63	1.72	2.03	2.19	1.56	0.47	-0.94	-2.188	8.6
Dakahlia	-2.7	-2.5	-1.72	-0.6	0.47	1.41	1.72	1.88	1.41	0.47	-0.94	-2.188	7.36
Giza	-2.7	-2.2	-1.41	-0.2	0.78	1.72	2.03	2.03	1.41	0.63	-0.94	-2.031	8.6

Table 4. Generation days of all *T. absoluta* spent of each month temperature.

Places	Janua.	Febr.	March	April	May	June	July	August	Septe.	Octob.	Nove.	Decem.
Mwnufia	54	52	45	34	27.0	18.7	16	18.0	19.0	28	40	50
Sharkia	56	52	46	37	34	22	18	20	24	31	42	53
Kalubia	54	50	45	34	27	18	17	22	26	28	40	50
Dakahlia	54	52	46	37	28	20	18	16	20	28	40	50
Giza	54	50	46	33	26	20	20	20	28	43	40	49

Table 5. Degree-days units DDU of *T.absoluta* from different governorates.

Places	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Menufia	396.5	397.5	400	404	407	410	411	411	410	406.5	402	398	404.46
Sharkia	306	307	309.5	313	316	319	321	320.5	318.5	315.5	311	307	313.67
Kalubia	396.5	397.5	400	404	407	410	411	411	410	406.5	402	398	404.46
Dakahlia	366.5	367	369.5	373	376.5	379.5	380.5	381	379.5	376.5	372	368	374.13
Giza	433.5	435	437.5	441.5	444.5	447.5	448.5	448.5	446.5	444	439	435.5	441.79

3.4. Degree Day Results

Table 5 includes DDU data explaining that *T. absoluta* thermal receivers to complete their life cycle. The data shall cover field sampling sites (Delta Governorate) and greenhouse sites (Giza, Upper Egypt). In current climatic conditions, the average DDU values for complete *T. absoluta* production were 404.46, 313.67, 404.46, 374.13, and 441.79 for Menufia, Sharkia, Kalyubia, Dakahlia, and Giza respectively, with Giza being the highest for both of these. The figures also refer to slight variations between locations due to small differences in the weather components. It is important to document the degree day based on the average temperature observed and to draw up a map of the data obtained for further use in a number of pest management topics [10, 16].

3.5. Insecticide Timing of Application Using DDs and DDU

Population structure, in particular larval size, age range, density, and field distribution of pests, is an important factor in the decision to use insecticides for the maintenance of insect pest control. By calculating the temperature requirements in degree days (dd) data, we can determine that the best time to apply insecticide is before 60 dd or between 60 and 150 dd. This proposal is endorsed by Tabikha [18] and Salama et al. [19]. Similarly, Zhang et al. [21] stated that insecticide treatments would be applied at the end of April–early May and at the end of May–early June to reduce the density of the nursery population of *Grapholita molesta* and *Adoxophyes orana*, respectively, in order to reduce the damage to the fruit in the orchards.

3.6. Weather Parameters and T. Absoluta Records of Field and Greenhouses Relationship

Weather data for each set of samples, according to the website information, included maximum and minimum temperatures in degrees Celsius, humidity (%), rainfall (mm), wind speed (km/h), daylight solar intensity (hours), and precipitation (days). These data were added to the number of field and greenhouse samples in Tables 6-11. The *T. absoluta* population increased from March to April by 50 percent of the total population. The change in population density peaks continued until July; the peak was in August, continued into September (100 percent of the population plus complete plant defoliation), and then declined in very small numbers until October. In the winter months of January, February, and March, it was noted that very few larvae were detected. Tomato leaf miner *T. absoluta*, capable of producing many generations without entering diapause, which causes seasonal changes in temperature, has been identified in temperate climates as a major threat to yield, as adaptive traits lead to widespread distribution and high economic losses [19, 22].

Table 6. Weather data of Kalubia Governorate plus the number of larvae gathered.

Month	T.abs.	Min.	Max.	Humed.	Rainfall	Windspeed	Day sun	Precipitation
Jan	2	10°C	19°C	56%	3.7mm	13kph	10.4h	1.1d
Feb	2	11°C	21°C	56%	3.5mm	13.7kph	11.1h	0.9d
Mar	15	12°C	24°C	56%	4.6 mm	14.3 kph	12h	0.8d
Apr	40	15°C	29°C	56%	2.3 mm	14.8 kph	12.9h	0.4d
May	40	18°C	32°C	56%	0.6 mm	15.1 kph	13.7h	0.1d
Jun	90	22°C	35°C	56%	0.1 mm	15.3 kph	14.1h	0.0d
Jul	170	23°C	36°C	56%	0	14.4 kph	13.9h	0.0d
Aug	270	24°C	36°C	56%	0	13.5 kph	13.2h	0.0d
Sep	190	22°C	34°C	56%	0.2 mm	13.3 kph	12.3h	0.0d
Oct	44	19°C	30°C	56%	1.7 mm	13 kph	11.4h	0.3d
Nov	12.0	15°C	25°C	56%	3.5 mm	12.7 kph	10.6h	0.6d
Dec	10.0	11°C	21°C	56%	3.6 mm	12.7 kph	10.2h	0.7d

The first survey carried out per 100 leaves every year for 12 months, data plotted as a population dynamic (Figure 2). The counts recorded over the 12 months for both fields and greenhouses corresponded to the increase in temperature from winter to summer over these months, which is a seasonal variation. Moreover, Dakahlia and Sharkia were the highest, and Menufia was the lowest among the field governorates (Figure 2). The number of samples from the immature stages in the greenhouses was higher than in the field, due to the small temperature increase in the greenhouses compared to the field conditions (Figure 3). The higher larval numbers were found in the middle to the end of the growing season because the plants were much grown and had many leaves.

Table 7. Weather data of Sharkia governorate plus number of larvae gathered.

Month	T.abs No.	Min.	Max.	Humed.	Rainfall	Windspeed	Day sun	Precipitation
Jan	3	9°C	19°C	56%	5.3mm	13.4 kph	10.4h	1.4d
Feb	6	10°C	20°C	51%	4.2mm	14.1 kph	11.1h	1.1d
Mar	50	12°C	23°C	47%	5.8mm	14.6 kph	12h	0.9d
Apr	120	15°C	27°C	44%	2.7 mm	14.7 kph	12.9h	0.4d
May	200	18°C	30°C	42%	0.7 mm	14.5 kph	13.7h	0.2d
Jun	307	21°C	33°C	45%	0	14.2 kph	14.1h	0.0d
Jul	387	23°C	35°C	51%	0	13.3 kph	13.9h	0.0d
Aug	487	23°C	34°C	54%	0.1 mm	12.8 kph	13.2h	0.0d
Sep	130	21°C	32°C	52%	0.1 mm	13.1 kph	12.3h	0.0d
Oct	40	18°C	29°C	54%	1.5 mm	12.9 kph	11.4h	0.4d
Nov	**10.0**	14°C	24°C	56%	2.9 mm	12.8 kph	10.6h	0.7d
Dec	**10.0**	10 °C	20°C	56%	4.7 mm	12.9 kph	10.2h	0.9d

The climate profile of Egypt as a whole is dry and hot, with a mild winter season with rain in coastal areas from October to March, and a hot and dry summer season with a maximum temperature of around 30°C from May to September. Temperatures in the desert regions vary widely, from 7°C at night to 43°C during the day in summer, but in winter they can reach 0°C at night and 18°C during the day. Precipitation is heaviest along the Mediterranean coast and falls steadily as you move inland and towards the desert. In the Mediterranean region, average temperatures range from 13°C to 21°C in winter and from 24°C to 32°C in summer. The Nile Valley and Delta region have a hot desert climate with temperatures averaging 30 to 40 ℃ during the summer and 14 to 20 ℃ during the winter, according to ReliefWeb [23] and other texts.

Table 8. Weather data of Menufia Governorate and the number of larvae gathered.

Month	T.abs No.	Min.	Max.	Humed.	Rainfall	Windspeed	Day sun	Precipitation
Jan	1	10°C	19°C	56%	3.9mm	13.1 kph	10.4h	1.0d
Feb	3	10°C	21°C	52%	3.7mm	13.8 kph	11.1h	1.0d
Mar	20	12°C	24°C	48%	4.3mm	14.3 kph	12h	0.8d
Apr	40	15°C	29°C	45%	2.3mm	14.8 kph	12.9h	0.4d
May	50	18°C	32°C	43%	0.6mm	15.1 kph	13.7h	0.2d
Jun	60	21°C	35°C	47%	0.1mm	15.4 kph	14.1h	0.0d
Jul	34	23°C	35°C	53%	0	14.7 kph	13.9h	0.0d
Aug	134	23°C	35°C	55%	0	13.7 kph	13.2h	0.0d
Sep	123	22°C	34°C	53%	0.1mm	13.4 kph	12.3h	0.0d
Oct	27	19°C	30°C	55%	1.7mm	13 kph	11.4h	0.3d
Nov	**15.0**	15°C	25°C	56%	3.5mm	12.8 kph	10.6h	0.7d
Dec	**10.0**	11 °C	21°C	57%	3.7mm	12.8 kph	10.2h	0.8d

The humidity ranged from 36% to 59% during the sampling period of 2018-2023, while the mean temperature was between 9°C and 24°C, and the maximum temperature ranged from 19°C to 36°C. The number of immatures counted in each open field represents the Delta samples and the greenhouse samples of the higher part of Upper Egypt, which is a region of varying climate. Where the population dynamics of greenhouse samples were more extensive than in other samples, the results were similar to Ata and Megahed [4] with a greater increase in survival, growth rate, reproductive success and overall life-cycle of *T. absoluta* at moderate to high humidity. Although high levels of moisture may encourage the growth of fungal pathogens affecting *T. absoluta*, low moisture conditions may inhibit hatching and larval development, thus reducing the pressure on the crop by the pests [24].

Table 9. Weather data of Dakahlia Governorate and the number of larvae gathered.

Month	T.absoNo.	Min.	Max.	Humed.	Rainfall	Windspeed	Day sun	Precipitation
Jan	5	10°C	19°C	59%	5.8mm	13.9 kph	10.4h	1.6d
Feb	1	10°C	20°C	55%	4.8mm	14.7 kph	11.1h	1.3d
Mar	20	12°C	23°C	52%	4.3mm	15.1 kph	12h	1.0d
Apr	60	15°C	27°C	48%	2.8mm	15.4 kph	13h	0.5d
May	160	18°C	31°C	47%	0.6mm	15.3 kph	13.7h	0.2d
Jun	210	21°C	34°C	50%	0	15.4 kph	14.1h	0.0d
Jul	290	23°C	34°C	56%	0	14.9 kph	13.9h	0.0d
Aug	390	24°C	34°C	58%	0	13.9 kph	13.2h	0.0d
Sep	150	22°C	33°C	56%	0.1mm	13.5 kph	12.3h	0.0d
Oct	60	19°C	30°C	58%	2.0mm	13.4 kph	11.4h	0.3d
Nov	20.0	15°C	25°C	59%	3.5mm	13.4 kph	10.6h	0.8d
Dec	10.0	11 °C	21°C	59%	5.2mm	13.5 kph	10.2h	1.1d

Table 10. Weather data of Giza governorate and number of larvae gathered (greenhouses samples).

Month	T.abs No.	Min	Max	Humed.	Rainfall	Windspeed	Day sun	Precipitation
Jan	5	10°C	19°C	54%	3.5 mm	13.2kph	10.5h	0.9d
Feb	10	11°C	21°C	47%	3.7 mm	13.9kph	11.1h	0.9d
Mar	70	13°C	24°C	42%	4.9 mm	14.7 kph	12h	0.8d
Apr	200	16°C	29°C	37%	1.8 mm	15.5 kph	12.9h	0.3d
May	300	19°C	32°C	36%	0.4 mm	16.1 kph	13.7h	0.1d
Jun	470	22°C	35°C	40%	0.1 mm	16.2 kph	14h	0.0d
Jul	550	24°C	35°C	45%	0	15 kph	13.9h	0.0d
Aug	620	24°C	35°C	47%	0.1 mm	14.3 kph	13.2h	0.0d
Sep	580	22°C	33°C	48%	0.4 mm	14.5 kph	12.3h	0.1d
Oct	300	20°C	30°C	52%	2.1 mm	13.9 kph	11.4h	0.4d
Nov	**70.0**	15°C	25°C	54%	5.1 mm	13.1 kph	10.6h	0.6d
Dec	**10.0**	12 °C	21°C	55%	4.4 mm	12.9 kph	10.3h	0.8d

Figure 1

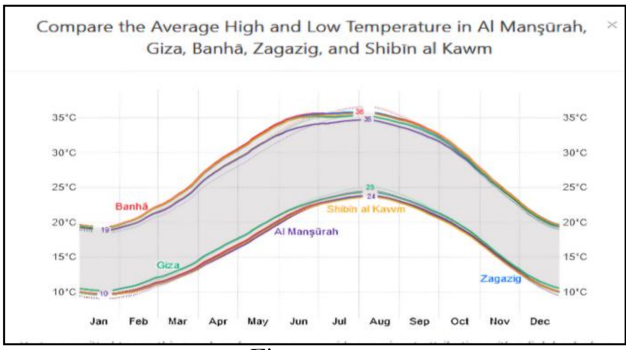

Figure 2

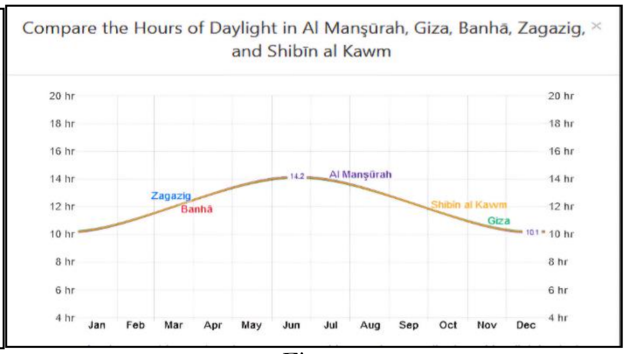

Figure 3

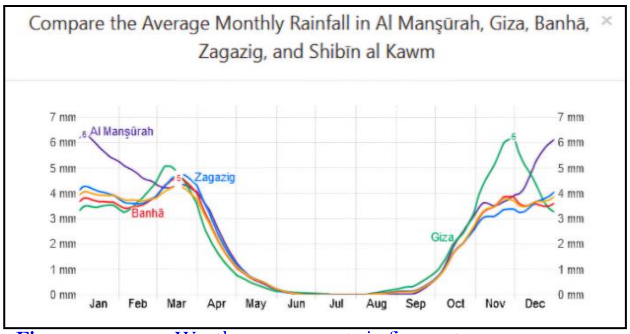

Figure 4

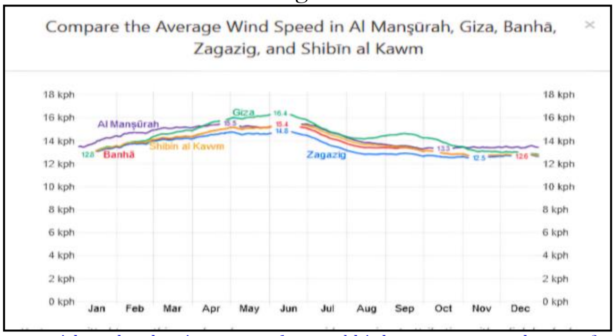

Figure 1, 2, 3, 4. Weather components in figures to compare governorates with each other in average low and high temperatures, hours of daylight, (2) average monthly rainfall, (3) and wind speed (4) to show differences. The Egyptian weather components of the tested sample sites (Mansurah, Giza, Banha, Zagazig, and Shebin-el-Kom) of each governorate (Dakahlia, Giza, Kalyubia, Sharkia, and Menoufia) are compared to identify differences.

3.7. Compare Some Governorate Weather Conditions Each Other

For the quantification of the differences between the candidate governorates of this study in weather data, illustrated graphs (Figures 1, 2, 3 and 4) of daylight hours, average monthly rainfall, wind speeds and muggy conditions were provided for the five sampling locations of *T. absoluta* sampled (Mansoura, Giza, Banha, Zagazig and Shebin-Alkum). These data showed small differences between those places that are the closest to each other in the Nile Delta in terms of agricultural practices, such as the Hassan and Omran [25] study on the diversity of soil and vegetation in Egypt. Figure 5. Two types of plotted data charts were included. Firstly, the dotted lines represent the mean value of each current weather factor (humidity, absolute humidity, sunshine hours, minimum temperature, and rainfall capacity) of Giza governorate at sample times. Secondly, the column bar represents the mean number of larvae gathered from greenhouse samples (Giza) in 2018-2020 and 2023. This data displays the greenhouse population dynamic chart from 2018 to 2023. The figure highlights the relationship and the correlations, which are either positive or negative, where the statistics of the correlation data are found in Tables 11-12.

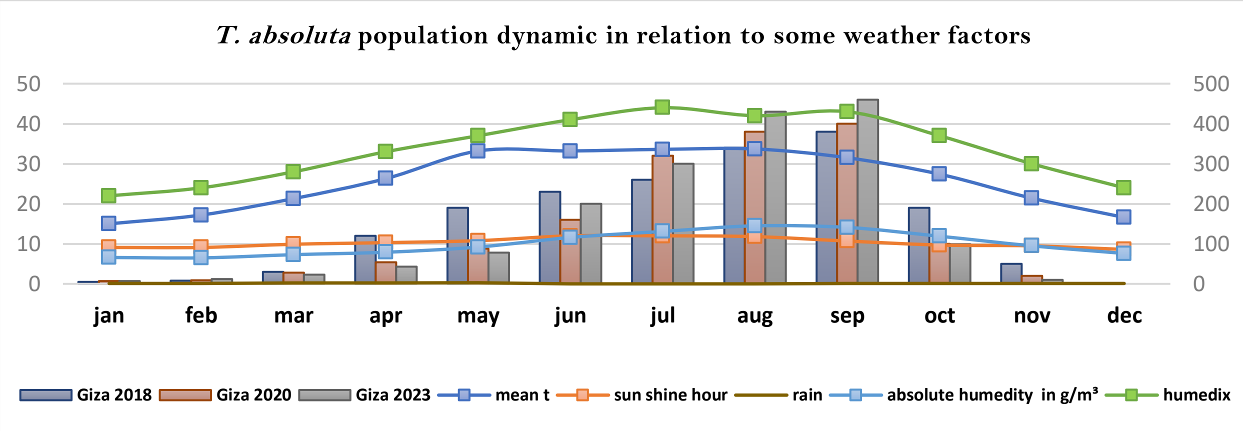

Figure 5. The figure contains the mean value of each current weather factor (humidity, absolute humidity, sunshine hours, minimum temperature, and rainfall capacity) of Giza governorate at sample times (the line dotted) and includes the mean number of larvae gathered from greenhouse samples (Giza) in 2018-2023 (column bar), representing the population dynamics from 2018 to 2023. The figure spot on the relationship and the correlations is positive (statistics of correlation data in Tables 11 and 12).

3.8. Statistical Analysis of the Survey Data

Tables 12 and 13, which include statistical analysis in correlation coefficients, show the relationship between the weather and the population density and the number of pests in the field or in the greenhouse. The larval population data refers to high correlation values between the number of infestations and weather factors, with the exception of wind speed. The values of the daily sunrise for Giza, Dakahlia, Menufia, Kalubia, and Sharkia ranged from 0.644, 0.59, 0.299, 0.337, and 0.68, respectively. However, the correlation values for temperature ranged from 0.789, 0.78, 0.594, 0.736, and 0.72 for the same configuration. The relationship with rainfall was positive and significant. Non-significant values were found for mean temperature, relative humidity, and sun hours. These results are in line with the figures from Chavan et al. [26].

Table 11. Correlation coefficient of Giza, Dakahlia, and Menufia governorates' infestation and meteorological factors' relationships with *T. absoluta* incidence.

Weather	Giza			Dakahlia			Menufia		
Parameter	Corr. Coeff	P value	R	Corr. Coeff	P value	R	Corr. Coeff	P value	R
Min t.	0.789	0.0041	0.883	0.78	0.0001	0.884	0.594	0.003	0.771
Max t.	0.789	0.0014	0.883	0.72	0.0005	0.847	0.579	0.004	0.761
Humed.	0.8035	0.0001	-0.89	0.0075	0.0789	-0.0866	0.0065	0.81	0.080
Rainfall	0.898	0.0001	0.947	0.72	0.0004	0.852	0.59	0.0036	0.767
Windspeed	0.119	0.148	0.344	0.028	0.602	0.168	0.0286	0.599	0.169
Day sun	0.644	0.0001	0.803	0.59	0.0034	0.769	0.299	0.065	0.547
Precipitation	0.789	0.0014	0.883	0.64	0.0018	-0.799	0.60	0.003	0.775

In addition to the simplified theoretical model adjustment for the minimum and maximum temperatures and the optimum lifespan of insects, Louthan and Morris [27] and Johansson et al. [28], some literature has used non-linear models to predict the outbreak and temperature variation relations of the green algae population *Tetraselmis tetrahele*, regimes, in addition to simplified theoretical degree-day model adjustments to generate a multispecies moth phenological model for IPM perception Damos and Savopoulou-Soultani [29] and Johansson et al. [28].

Table 12. Correlation coefficient of Kalubia and Sharkia governorates infestation and meteorological factors relationships with *T. absoluta* incidence.

Weather	Kalubia			Sharkia		
Parameter	**Corr. Coeff**	**P value**	**R**	**Coeff**	**P value**	**R**
Min t.	0.736	0.0004	0.858	0.72	0.0005	0.85
Max t.	0.650	0.0016	0.81	0.72	0.0005	0.85
Humed.	0.012	0.76	-0.101	0.062	0.433	-0.25
Rainfall	0.63	0.002	-0.79	0.58	0.004	-0.76
Windspeed	0.0086	0.77	0.093	0.0034	0.86	0.058
Day sun	0.337	0.048	0.58	0.68	0.0009	0.826
Precipitation	0.58	0.004	-0.76	0.61	0.0026	-0.784

The data in the Tables 14 and 15 show a multiple regression analysis to demonstrate the relationship between the occurrence of pests, density, and climatic factors. The dependent variable was the total number of larvae per holding, and the independent variable was regressed against the variable for height. Regression analysis was conducted using a generalized linear model based on standard deviations, errors, a probability ratio, and a chi-square test. The values refer to the steepest relationship with both the minimum and maximum temperatures across all sampling locations tested. However, the relationship with humidity was clear only in Giza, Dakahlia, Menufia, and Sharkia, but negative in Kalubia. The fault is documented and stored for the purpose of this study at minimum and maximum temperatures. A significant difference was found by ANOVA, with a Tukey test yielding a P-value of 0.05.

Table 13. Regression coefficient of Giza, Dakahlia, and Menufia governorates' infestation and meteorological factors' relationships with *T. absoluta* incidence.

	Giza				Dakahlia				Menufia			
Weather Parameter	**Regress Coeff**	**ANOVA F(p)**	**fit R**	**Estimated t(p)**	**Regress Coeff**	**ANOVA F(p)**	**fit R**	**Estimated t (p)**	**Regress Coeff**	**ANOVA F(p)**	**fit R**	**Estimated t(p)**
Min t.	189.1	0.55(0.6)	0.33	0.59(0.57)	292	5.7(0.025)	0.74	2.5(0.03)	64.4	3.1(0.09)	0.64	1.3(0.21)
Max t.	-385.5	0.89(0.4)	0.4	-1.1(0.31)	292	2.3(0.156)	0.58	1.5(0.18)	78.6	2.1(0.17)	0.56	1(0.33)
Humed.	605.1	7.7(0.01)	0.79	3.5(0.006)	421	1.7(0.23)	0.53	1.2(0.25)	61.0	1.2(0.33)	0.46	0.4(0.69)
Rainfall	227.4	1.8(0.21)	0.53	1.5(0.17)	-177	2.1(0.17)	0.56	-1.8(0.11)	-68.7	2.2(0.16)	0.57	-2(0.12)
Windspeed	-1125	6.4(0.019)	0.76	-3.3(0.01)	-988	3.9(0.06)	0.69	-2.4(0.04)	-157.4	1.36(0.3)	0.48	-0.8(0.4)
Day sun	-1104	12.9(0.00)	0.86	-4.9(0.00)	-352	1.2(0.34)	0.46	-0.99(0.3)	-43.3	1.1(0.4)	0.44	-0.3(0.7)
Precipitation	241	1.4(0.3)	0.48	6.3(0.00)	-146	2.0(0.18)	0.56	-1.7(0.12)	-75.3	2.7(0.12)	0.61	-4.6(0.0)

Table 14. Regression coefficient of Kalubia and Sharkia governorates' infestation and meteorological factors' relationships with *T. absoluta* incidence.

	Kalubia				Sharkia			
Weather	**Regress**	**ANOVA**	**fit**	**Estimated**	**Regress**	**ANOVA**	**fit**	**Estimated**
Parameter	**Coeff**	**F(p)**	**R**	**t(p)**	**Coeff**	**F(p)**	**R**	**t(p)**
Min t.	68.2	1.2(0.445)	0.46	0.73(0.48)	322.95	6.0(0.022)	0.75	2.5(0.03)
Max t.	24.6	0.9(0.43)	0.47	0.2(0.85)	484.4	3.9(0.059)	0.68	2.1(0.03)
Humed.	-0.002	0.9(0.45)	0.41	-0.0(1.0)	323.4	1.3(0.33)	0.47	0.82(0.43)
Rainfall	-9.2	0.9(0.45)	0.41	-0.16(0.9)	-225.7	3.8(0.06)	0.68	-2.5(0.033)
Windspeed	-357.8	2.2(0.16)	0.6	-1.5(0.16)	-985.4	2.1(0.175)	0.57	-1.5(0.147)
Day sun	-235.7	2(0.18)	0.56	-1.47(0.17)	-143.6	0.79	0.39	-2.7(0.79)
Precipitation	-49.3	0.9(0.43)	0.41	-0.88(0.4)	-223.4	3.4(0.078)	0.65	-5.5(0.0004)

3.9. Future Climate Data (2025 and 2050) and T. Absoluta Density

Evaluation of the effects of climatic changes on insect incidence, abundance, and building density of populations by the method of accumulation of the thermal requirements for development resulted in temperature data for each governorate attained from a website database for forecasting spatial and temporal variations and to predict the future distribution of *T. absoluta* trends of threats in ecosystems under current and expected climatic changes at 2050. Population peaks will change to develop more rapidly according to the percent increases in environmental temperature. The fact about temperature increases, as found by Fouad et al. [1], using the Mann-Kendall test to detect trends, confirmed the increase in annual temperatures in Egypt, with an increase of 0.87°C.

And the highest warming trend in the summer season, with an increase of 1.35°C, and the lowest warming trend in the winter season, with an increase of 0.46°C. From Table 15, it can be concluded that the new calculations, due to rises in temperature in 2050, indicate that the number of generations per year produced will be 9.72, 9.58, 9.1, 8.48, and 7.53 for Kalubia, Giza, Menufia, Dakahlia, and Sharkia, respectively. This means that rises in temperature of about 0.46 °C in winter months and 1.35 °C in summer months will result in an additional one generation per year (Table 15), and after 25 years, the generation per year will reach 9+25=34 per year. These results agree with Salama et al. [19].

Table 15. Number of generations/years according to rises in month's temperature (1.35 in summer and 0.46 in winter) for one year only of all *T. absoluta* samples from field and greenhouse to predict the number of generations in 2050 climate.

Places	Janua.	Febr.	March	April	May	June	July	August	Septe.	Octob.	Nove.	Decem.	g/year
Menufia	-2.6	-2.3	-1.49	-0.2	0.84	1.77	2.09	2.09	1.77	0.54	-0.87	-2.116	9.1
Sharkia	-2.7	-2.4	-1.65	-0.6	0.52	1.46	2.09	1.93	1.3	0.23	-1.18	-2.428	7.53
Kalubia	-2.6	-2.1	-1.49	-0.2	0.84	1.93	2.24	2.4	1.77	0.54	-0.87	-2.116	9.72
Dakahlia	-2.6	-2.4	-1.65	-0.6	0.68	1.62	1.93	2.09	1.62	0.54	-0.87	-2.116	8.48
Giza	-2.6	-2.1	-1.33	-0.1	0.99	1.93	2.24	2.24	1.48	0.7	-0.87	-1.959	9.58

The generation days with the expected future climate conditions in 2050 and 2100 will decline by about two to three days from the current climate in 2025, and from 6 to 8 days at 2050, respectively. In January, it took 52 days and will change to 53 days, and in August, it took 16 days and will change to 14 days in 2025.These results agree with Damos et al. [30], Damos et al. [20], and Salama et al. [19]. But Tabikha [18]. It is expected that *T.absoluta* existence will be restricted in the North Delta and Western North Coast governorates during the warm seasons of 2050. It is also expected that adults' longevity will observably decrease by 2-3 days in 2050. Figure 6 temperature rises of current and past weather plotted through the upper and lower lines express the low and high temperatures, and the in-between line is the average temperature plotted to quantify the elevated temperature value gradually from the year 1940 to 2020, according to weather website data downloaded.

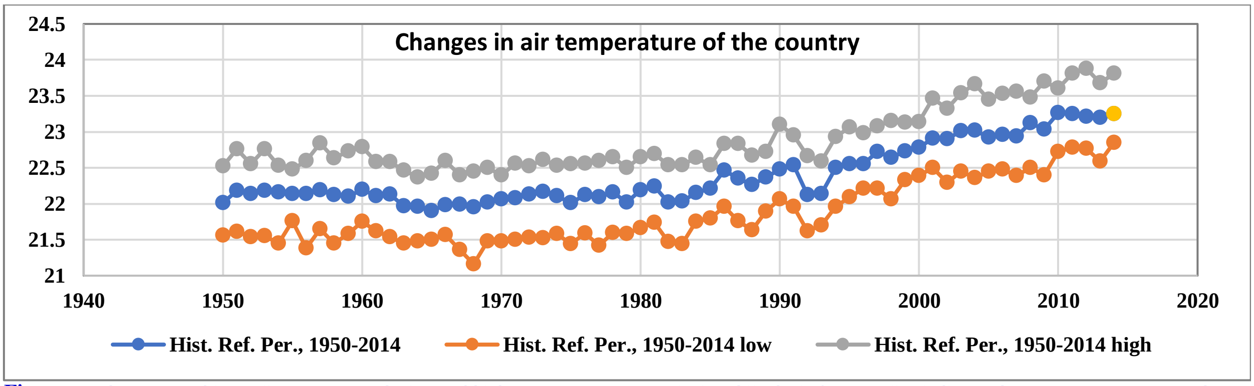

Figure 6. The upper and lower lines represent the low and high temperatures, respectively, while the in-between line indicates the average temperature. These lines are plotted to quantify the elevated temperature values from 1940 to 2020 on a yearly basis, based on data downloaded from weather websites, reflecting Egyptian weather patterns.

Figure 7 Average temperature of all Egypt governorates areas was configured in 3 color pictures to show differences between the average temperature of the past weather (1940), the current weather (2020), and projected changes in 2025. The charts and data are sourced from the following website: https://meteologix.com/eg/modelcharts/standard.

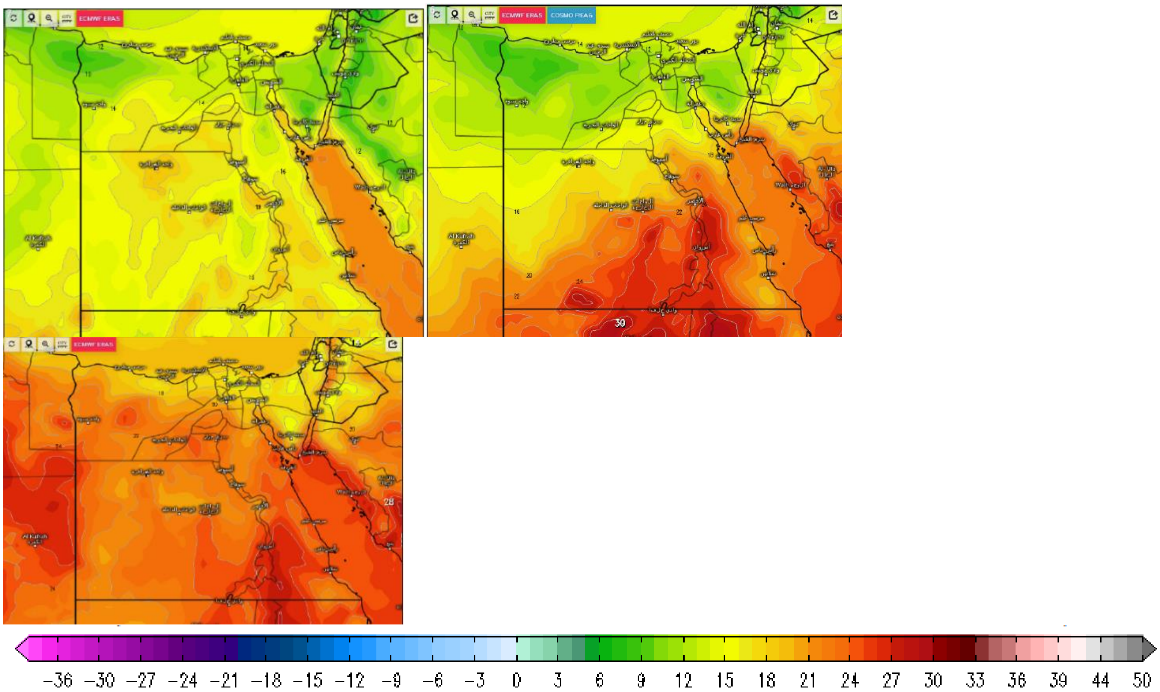

Figure 7. Temperature rises in Egypt were extended to the whole Egyptian area smoothly according to https://meteologix.com/eg/model-charts/standard.

Temperature rising sequences in review as, at hot summer, the crop-specific pesticide programs showed an increase in pesticide use frequency compared to the season before, as well as *Drosophila suzukii* invasion in the blackberry planting [31]. The greatest effect of coccinellids in reducing total aphid numbers of *Sitobion avenae* depended on temperature rises occurring, Skirvin et al. [32].

4. CONCLUSION

Several climatic factors, such as humidity, light intensity, and rainfall, may influence the development of pests and are a basis for studying forecasting issues in light of field observations, taking into account geographical variation. Evaluation of the opposite effects of climate change on insect abundance, population density, and population dynamics, based on the accumulation of thermal development requirements, is an urgent matter. The number of generations and generation days, as well as the timing of insecticide application depending on the insect's life cycle, are of key importance. Additionally, the preparation of predictive information is known as the insect phenological model (phase evolution over time), used in the calculation of species-specific degree days (DDs), which are correlated with key physiological events such as egg hatching or adult flight. All insects have a lower and upper temperature threshold, below or above which development ceases.

Funding: This study received no specific financial support.
Institutional Review Board Statement: Not applicable.
Transparency: The author states that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

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